Analysis of the influence of nonlinear loads on power dissipation of LV-cables

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***Abstract*— The cumulative harmonic currents of a large number of non-linear single phase loads, such as PC's, monitors and other equipment will result in cumulative triple n-harmonics in neutral conductor. So, the nonlinearity of loads affects the current distribution in both phase and neutral conductor cores in three phase power supply systems. Consequently both extra power dissipation in neutral conductor and higher cable temperature directly influence power dissipation of the whole cable.**

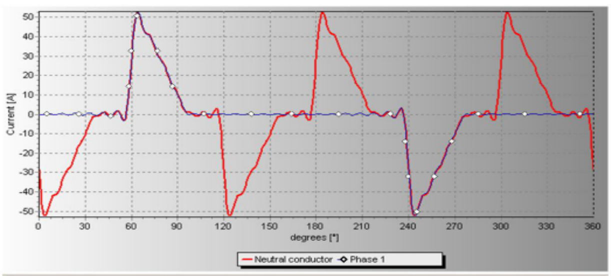
***Index Terms*—Power consumption, Losses, Power cable dissipation, Power system harmonics, Power quality**

I. Introduction

Nowadays nonlinear loads (compact fluorescent lamps, computers, variable speed drives,…), mostly used with the aim of rational energy use, are very common. These loads, producing harmonic currents, yield high neutral conductor currents (Fig. 1). Theoretically in case of balanced and symmetrical load conditions the ratio of the neutral conductor current and the phase current can increase up to: $I_N/I_{phase}=\sqrt{3}$.

In practice however, a neutral conductor current will never reach this value (Fig. 2).

Studies on bad power quality conditions mention overheating of cables, due to nonlinear loads. Consequently power cable dissipation must have increased in these cases. An analysis for symmetrical balanced loads in both linear and non linear load conditions is worked out in order to evaluate cable dissipation.



		Neutral conductor	Phase 1	Phase 2	Phase 3
Irms	[A]	25.278	14.589	14.589	14.589
Ifund	[A]	0	8.224	8.224	8.224
Ipeak	[A]	52.942	52.827	52.827	52.827
CF(I)	-	2.09	3.62	3.62	3.62
THD(I)	[%]	infinite	146.52	146.52	146.52
P	[W]	-	1.8E3	1.8E3	1.8E3
PF	-	-	0.536	0.536	0.536
dPF	-	-	0.952	0.952	0.952
S	[VA]	-	3.356E3	3.356E3	3.356E3

Fig. 1 Neutral conductor and phase current for symmetrical balanced load (100 compact fluorescent lamps per phase)

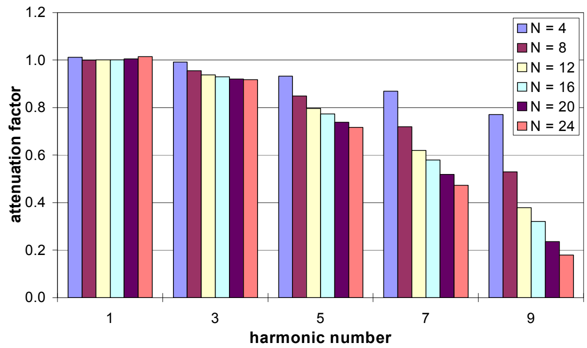


Fig. 2 Attenuation factors for harmonic currents with respect to a higher number of non linear loads

II. Analysis

A. Point of view

Normally, in the world of distribution, power losses in cables are well known and cable cross sections are well designed for sine wave conditions. However in the typical industrial plant and even more specific in distribution of LV energy in administrative buildings, other phenomena will occur. Due to both, voltage distortion and non linear load conditions, neutral conductor currents can arise to quite high values. Power dissipation in cables will be affected. Not only the increase of losses due to the neutral conductor but also a higher cable temperature will further increase power losses in cables.

B. Calculations

The power dissipated in the cable, which represents the emitted heat, is calculated per core from its series resistance and the loaded rms-current for each phase:

$$P_A = RI_A^2 \quad [W/m] \tag{1}$$

with R the cable resistance [Ω/m]. The total power losses generated in the cable is given by the sum of eq. (1) for both phase and neutral conductor.

The cable resistances are temperature dependent according to

$$R = R_{20}\left(1+\alpha\left(T-20\right)\right) \tag{2}$$

with R_{20} [Ω/m] the reference resistanceat 20°C, and T [°C or K] and α the temperature respectively temperature coefficient of the conductor material (copper or aluminium, both approx. 0.004/K).

Considering a LV cable of the type EVAVB of 4*25mm² has a given resistance of 0.727Ω/km @ 20°C (NBN C33-121). Current limits are given as $I_{th\ air}$ = 110A and $I_{th\ unther\ ground}$ = 130A. For a given lengh of 300m and an estimated cable temperature of 60°C a voltage drop of 10% will be found for a cable load of 100A.
Power dissipation in the cable is found using eq. (1) and (2) and amounts up to 2530W/phase or 7590W for the three phases in the power cable. Assuming full load conditions during a whole year, cable power losses will give an energy consumption of 66.5 MWh/y.
In case of a non linear symmetric and balanced load condition (as given in fig. 3), it can be proved that only triple n harmonics are found in the neutral conductor. The magnitude of the neutral conductor dissipation is function of the weight of the triple n harmonics. In worst case conditions it is proven that the ratio of neutral and phase conductor current can reach a value of 1.73. In this particular case neutral conductor dissipation can amount up to tree times phase dissipation.

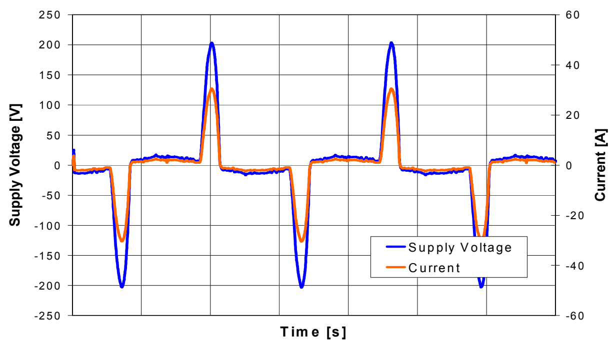


Fig. 3 Supply Voltage and current waveform measured on high number of PC loads and used as test signal

These extra losses will create two phenomena. The first is found in an increase of cable temperature due to the fourth source of heating. Consequently cable resistancewill also increase, representing a second phenomenon. A higher cable resistance will also give higher power losses and higher power losses will give higher cable temperatures.
It is shown (Table 1 and Fig 4, 5) in both experimental and measured set ups (XVB 2.5mm²) that the cable temperature can increase by more than 30K due to the non linearity of the load.

Table1: Copper temperature: measured, calculated and simulated for a XVB 4*2.5mm for both linear and non linear load

I_{phase} [A]	Meas [°C]		Calc [°C]		Sim [°C]	
setpoint	Lin.	n lin.	lin.	n lin.	Lin.	n lin.
5	24.1	24.2	24.5	25.0	24.1	25.0
10	30.5	36.9	29.7	36.5	29.7	36.2
15	47.5	60.6	45.9	58.0	45.9	57.5
20	69.2	98.9	66.6	99.4	66.2	96.6
25	98.3		99.0		96.4	

Power losses are calculated for a realistic neutral conductor current of 1.5 times phase current (measured on a realistic balanced symmetrical non linear load). In this case, due to higher cable temperature, losses in phase wires will increase with approx 12%, caused by the temperature coefficient of the cable resistance. On the other hand extra neutral conductor losses are found of 2.25 times phase power losses. Global energy losses of 66.5 * 1.12 + 55.8 = 130MWh/y are found.

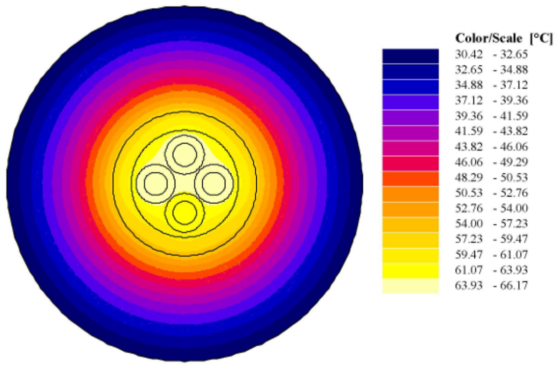


Fig. 4 Simulated temperature distribution for balanced symmetric sine load 20A/phase (XVB cable 4*2.5mm²)

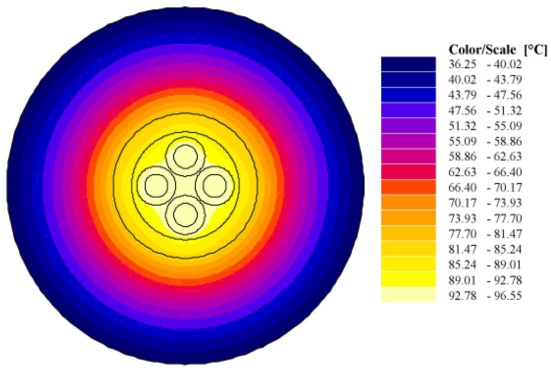


Fig.5 Simulated temperature distribution for balanced symmetric nonlinear load 20A/phase (XVB cable 4*2.5mm²)

Figures given in higher discussion are extreme values especially in case of the non linear load conditions. However, for lower cable loads same conclusions about power losses caused by neutral conductor currents can be drawn.

III. Conclusion

From the results found in this analysis, it can be concluded that power dissipation in cables can reach higher values than mentioned in the past. Especially in cases of non linear loads, asymmetric and unbalanced load conditions the neutral conductor can be overloaded. These overload conditions cause higher energy losses and possibly even worse fire hazard.
Not the distribution sector has to deal with these problems, but industrial plants (especially administrative buildings) have to take into consideration both problems of overheating and excessive power losses due to non linear single phase loads.